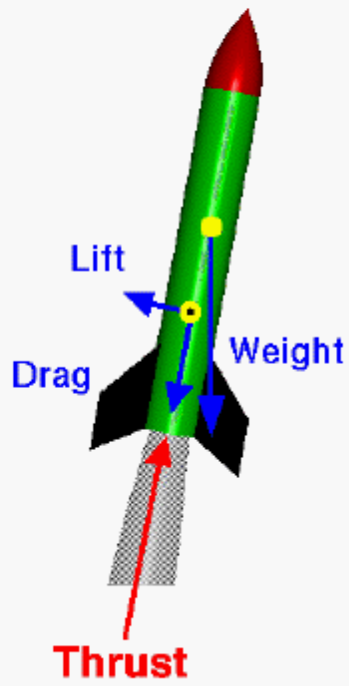


# Capítulo 5. TRAJETÓRIA



## *Model Rocket Thrust*

Glenn  
Research  
Center





# Forces During Liftoff

Glenn  
Research  
Center

Thrust and Weight depend on time (t).

Lift and Drag depend on velocity.

Velocity is zero (or low).

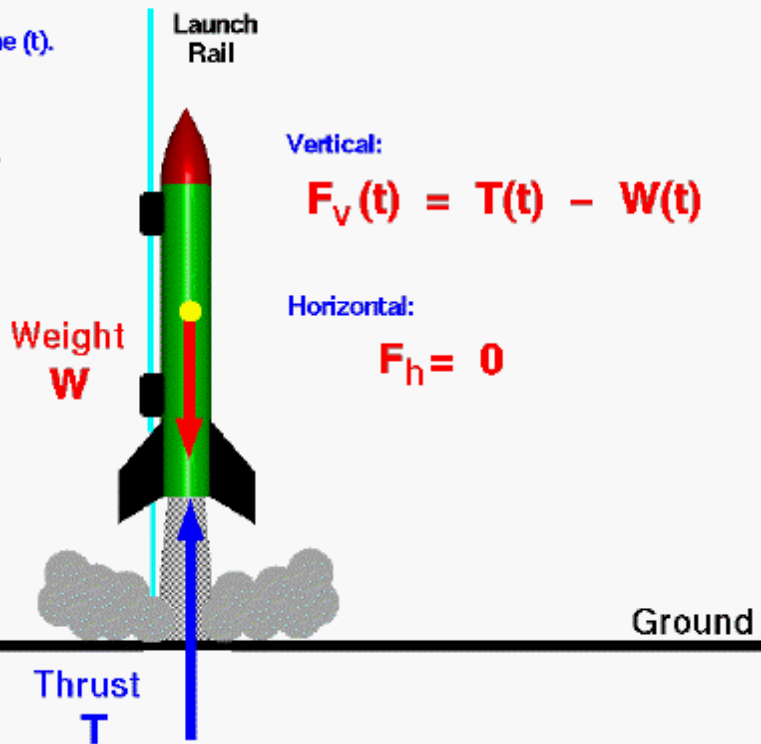
No Drag - No Lift (control).

Reason for launch rail.

Coordinates

Vertical - v

Horizontal - h



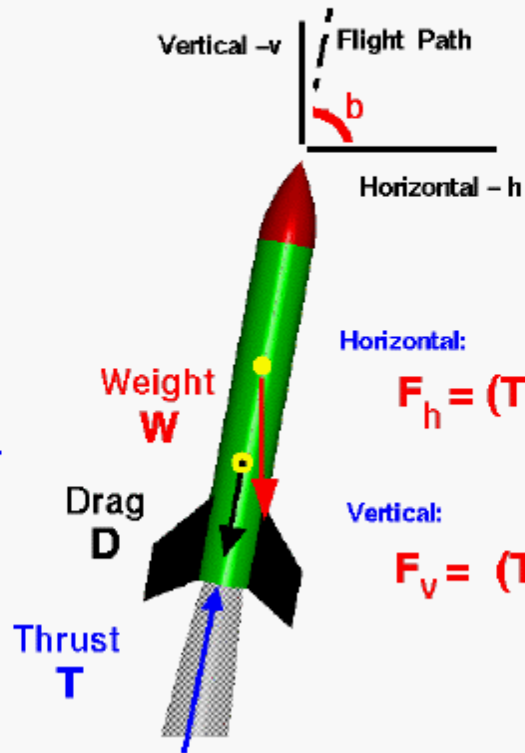


## Forces During Powered Flight

Glenn  
Research  
Center

Flight path inclined to horizontal by angle =  $b$

For rocket aligned with flight path, Lift is zero.



Horizontal:

$$F_h = (T - D)\cos b$$

Vertical:

$$F_v = (T - D)\sin b - W$$



## Forces During Coasting Flight

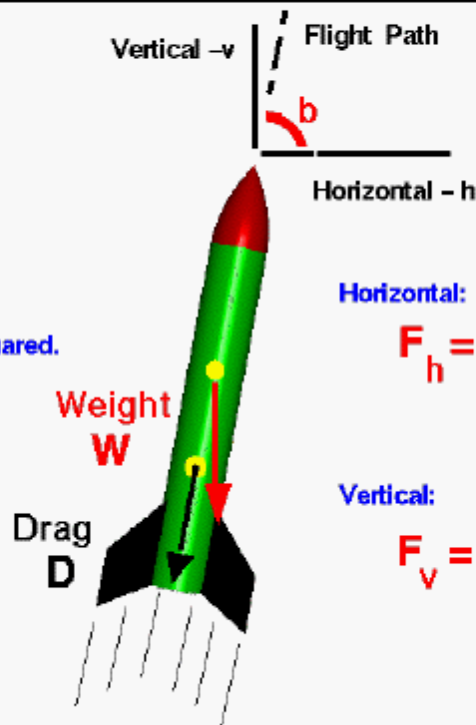
Glenn  
Research  
Center

Flight path inclined to horizontal by angle =  $b$

For rocket aligned with flight path, Lift is zero.

Drag depends on velocity squared.  
As velocity decreases, Drag decreases.

If rocket is descending, angle  $b$  is negative, and  $\sin b$  is negative.



Horizontal:

$$F_h = -D \cos b$$

Vertical:

$$F_v = -D \sin b - W$$



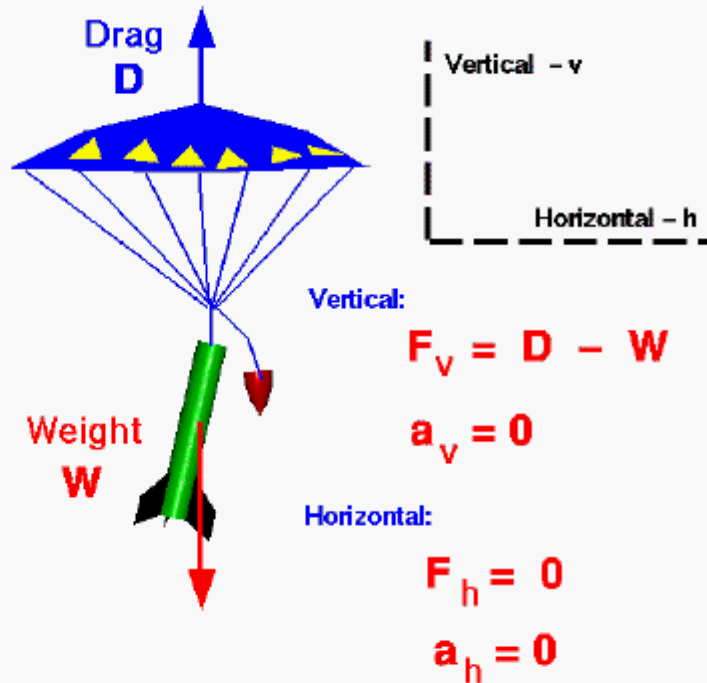
# Force and Acceleration During Recovery

Glenn  
Research  
Center

Only forces working are the aerodynamic drag of the system and the weight.

When  $D = W$ , no net external force acts on the system.

With no net external force, acceleration equals zero.





# Model Rockets

Measured Altitude

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Research  
Center

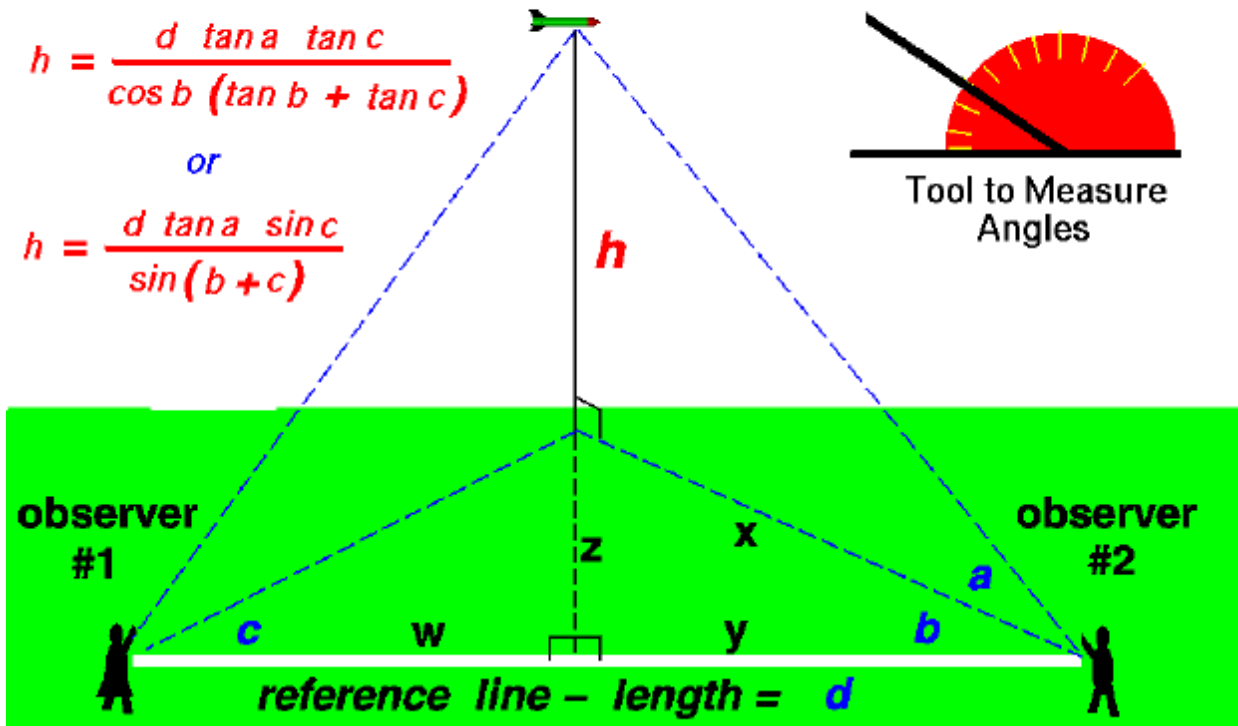
$$h = \frac{d \tan a \tan c}{\cos b (\tan b + \tan c)}$$

or

$$h = \frac{d \tan a \sin c}{\sin(b+c)}$$



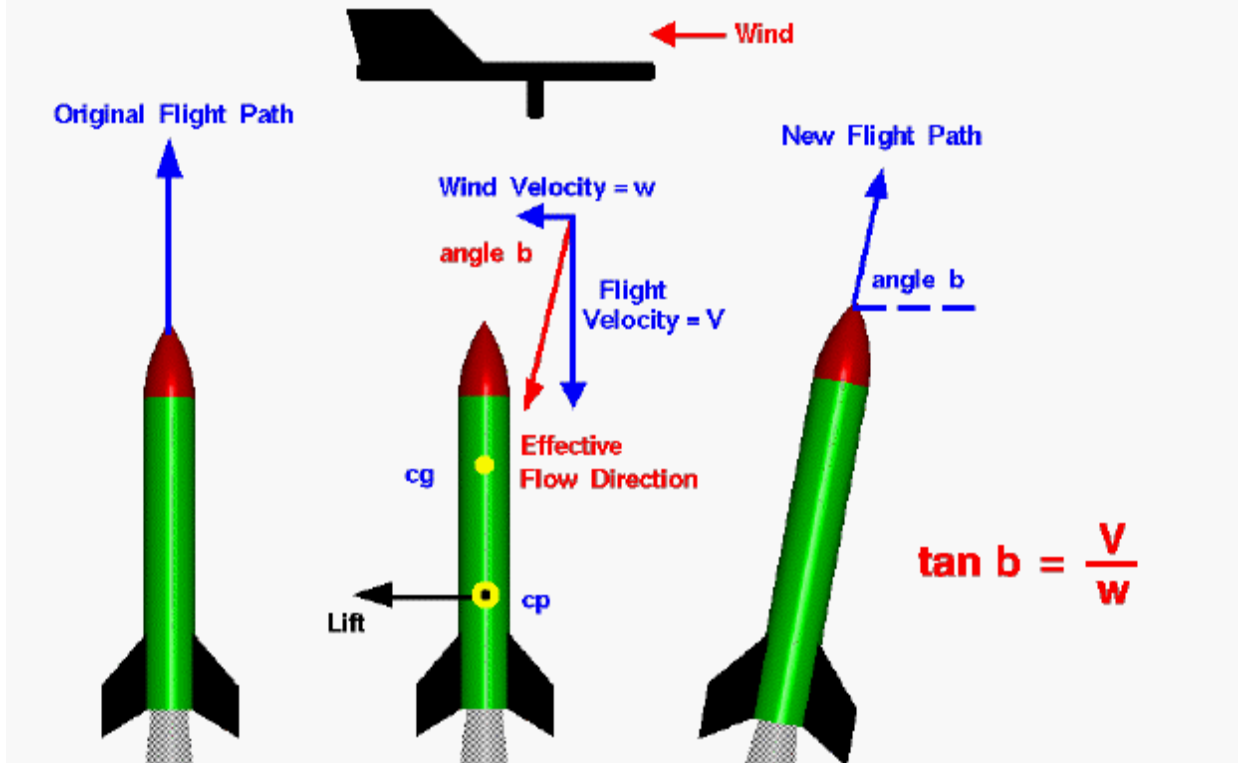
Tool to Measure  
Angles





# Weather Cocking

Glenn  
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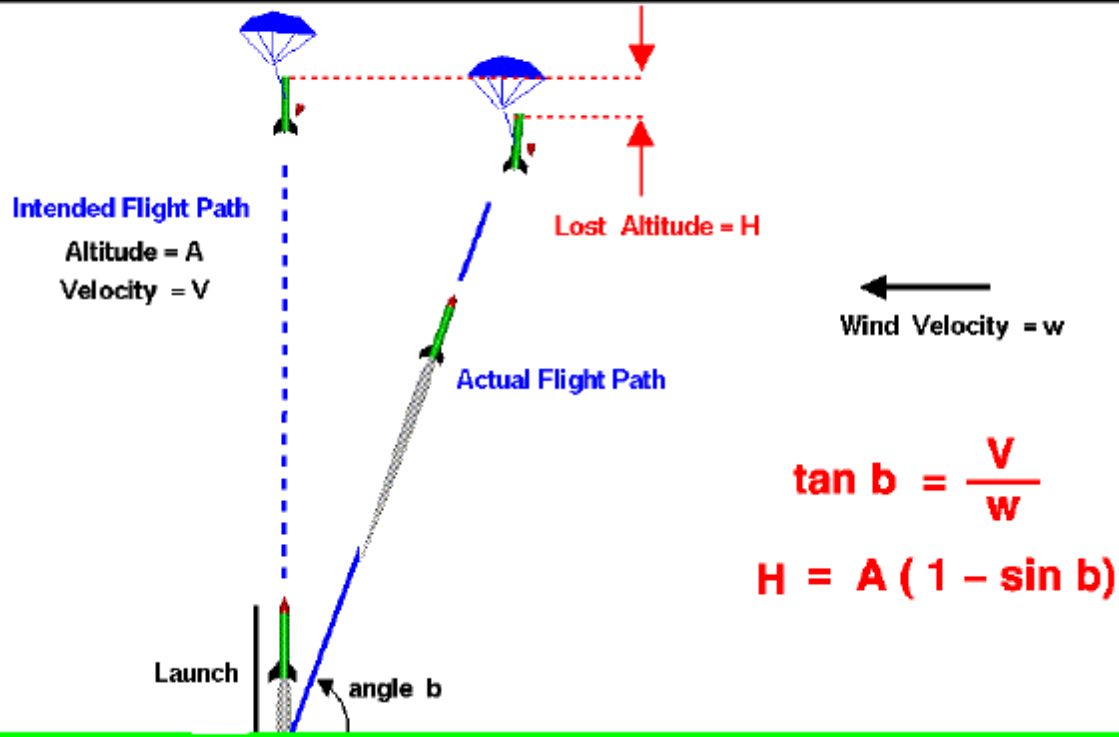




# Effects of Weathercocking

## Flight of a Model Rocket

Glenn  
Research  
Center





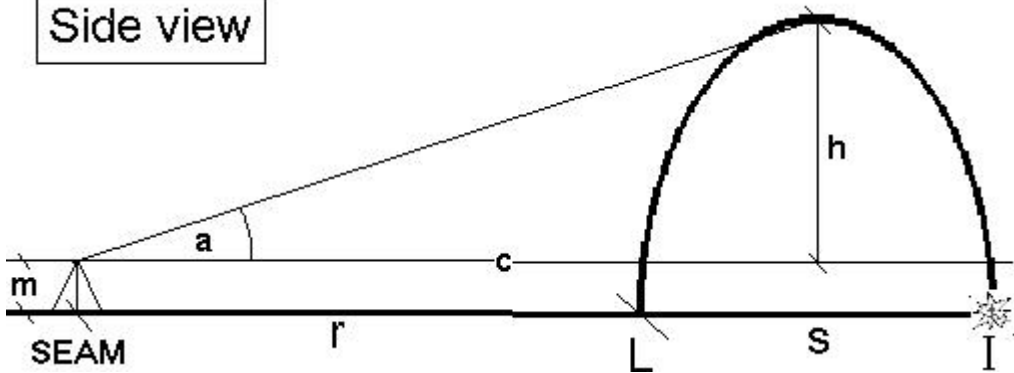
# SEAM Calculations

<http://waterrocket.uh-lab.de/seamcalc.htm>

SEAM = Simple, but Exact AltiMeter

This sketch shows the launching site:

Side view



$m$  = height of eyeline above launcher

$L$  = launcher

$I$  = impact

The basic formula is  $\tan a = h/c$ . Assuming the rocket goes straight up and down we can write

$$(1): h = r * \tan a$$

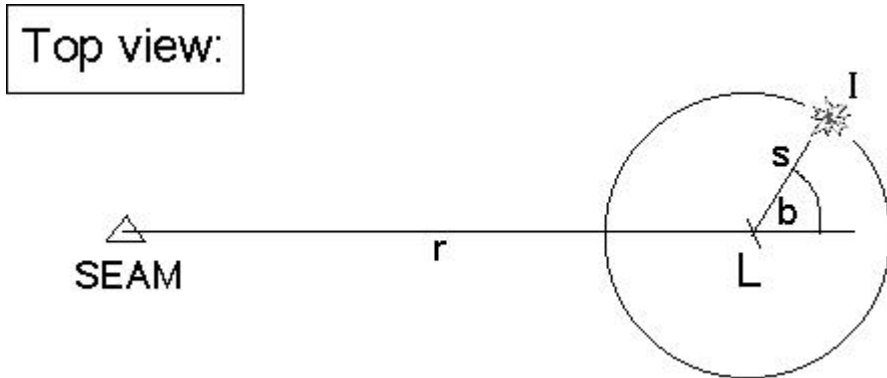
Usually the rockets land at some distance to the launcher due to side winds or non-vertical launches. This may affect the measured altitude, if we just use (1). If we assume that the rocket lands behind the launcher as shown in the sketch above, we get

$$(2): \tan a = h/(r+s/2)$$

We may watch the launch from an elevated standpoint,  $m$  meters above launch level. For the total altitude  $Alt$  of the rocket above ground level we get in this case

(3):  $Alt = m + h = m + (\tan a) * (r + s/2)$

However, the rocket may land not just behind the launcher, but anywhere:



So, after impact, we measure not only the angle  $a$  and the distance to the launcher  $s$ , but as well the angle  $b$ .

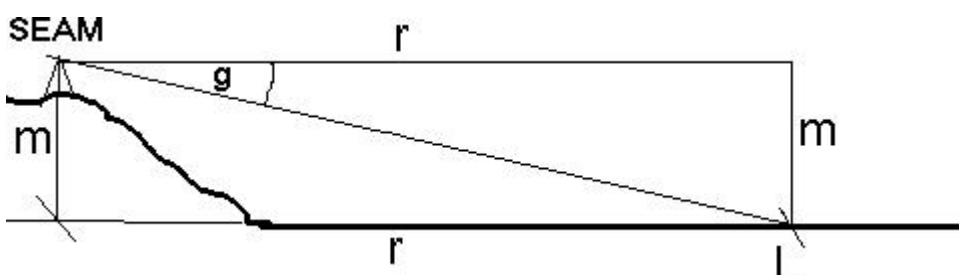
Depending on the angle  $b$ , the real altitude will be greater or smaller than the basic formula (1) with  $c = r$ . This is reflected in

(4):  $Alt = m + \tan a * (r + s/2 * \cos b)$

Equation (4) is a good approximation if no chute is used, meaning if the times for going up and down are similar. With a chute, the down time is much longer than the up time. To take this into account, we can write, assuming a constant side drift

(5):  $Alt = m + \tan a * (r + s * t_{up}/(t_{up} + t_{down}) * \cos b)$

Usually you can neglect  $m$ . But if you are watching from some elevated standpoint,  $m$  can be determined quite nicely as follows:



We approximate  $r$  by the measured distance between SEAM and the launcher  $L$ ; we measure the angle  $g$ . For  $m$  we get

$$(6): m = r * \tan g$$

Now let's do a real world

### EXAMPLE:

Before launch we determine  $m = 3,34$  m and  $r = 40$  m. Angle  $a$  is in all cases  $65^\circ$ . We assume  $t_{up}$  is similar to  $t_{down}$ .

Case 1: no matter where the rocket landed, we use formula (1) and  $Alt = h + m$

Case 2: the rocket landed 15,3m behind the launcher, at  $b=5^\circ$ . Formula (4).

Case 3: the rocket landed 15,3m between the launcher and the SEAM, at  $b=185^\circ$ .

Formula (4).

Case #	m	a (°)	r	s	b (°)	=Altitude
1)	3,34	65	40	0	0	89,1
2)	3,34	65	40	15,3	5	105,5
3)	3,34	65	40	15,3	185	72,8

As one can see, the results are quite different, depending on where the rocket landed.

**Hint:** If you are new to trigonometric calculations, try first if  $\tan(45^\circ)=1$ . If it is not, your calculator or data sheet probably uses radians instead of degrees. In this case try, if  $\tan(45 * \text{Pi}/180)=1$ . If so, use that enhancement  $[\text{angle in degrees}] * \text{Pi}/180$  each time when an angle has to be entered.

[Altimeter: SEAM calculations to determine the altitude of your rocket][[Altimeter: SEAM \(Simple, but Exact AltiMeter\) pictures](#)][[Altitude Measurement Method Comparison](#)]